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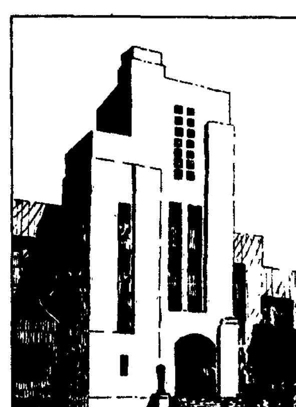
THE DAVID W. TAYLOR MODEL BASIN

UNITED STATES NAVY

THE HYDRODYNAMIC PROPERTIES OF THE AIR-TOWED SONAR HOUSING

BY LEO F. FEHLNER



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6 THE HYDRODYNAMIC PROPERTIES OF THE AIR-TOWED SONAR HOUSING,

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THE HYDRODYNAMIC PROPERTIES OF THE AIR-TOWED SONAR HOUSING

ABSTRACT

The factors involved in the hydrodynamic design of the air-towed sonar housing, using weight to obtain the design depth, and the results of tests giving information on the drag, cavitation, and stability characteristics are reported.

INTRODUCTION

A project was established (1)* at the David Taylor Model Basin to design a housing for sonar equipment to be towed by aircraft at speeds up to 50 knots. To gain any appreciable advantage over other methods of searching with sonar, it was considered essential to increase the search rate over that possible with surface vessels. Because the search rate increases with quietness and towing speed, the sonar housing described has been designed in an attempt to realize the advantages of both quietness and high speed.

A housing embodying the desired characteristics was designed by analytical methods. To prove this design, two models were built and tested at the Taylor Model Basin.

The results of the tests are given, but since the present report is concerned chiefly with the hydrodynamic characteristics of the air-towed housing, details of the conduct of the tests are omitted. The development of the cable fairing and the problem of towing will be discussed in later reports.

GENERAL DESIGN CONSIDERATION

The towed housing developed for the project is shown schematically in Figure 1. Its shape is defined by Tables 1 and 2. The considerations which determined the overall design fall into three groups, namely, the considerations pertinent to the streamlined housing, the stabilizing fins, and the location of the tow point.

HOUSING

Observations regarding the noise produced by a body moving in water have shown that cavitation is a source of noise of high intensity and becomes important at about 80 per cent of the speed at which visible cavitation would be expected (2).

To ensure that the sonar housing has a cavitation speed well above the highest speed anticipated in actual use, the housing was chosen to be a

* Numbers in parentheses indicate references on page 9.

TABLE 1

Offsets for Towed Housing, See Figure 1

All dimensions are in inches.

X	Y	X	Y
0	0	59.50	8.409
0.595	1.284	65.45	8.210
1.19	1.810	71.40	7.900
2.38	2.545	77.35	7.478
4.76	3.555	83.30	6.944
8.33	4.619	89.25	6.299
11.90	5.416	95.20	5.542
17.85	6.415	101.15	4.673
23.80	7.147	107.10	3.690
29.75	7.687	110.67	3.022
35.70	8.075	113.05	2.516
41.65	8.333	115.43	1.920
47.60	8.471	117.81	1.091
53.55	8.496	119.00	0.000
Nose Radius = 1.392 inch			
Tail Radius = 0.4923 inch			

TMB-EPH body of revolution of the type described in Reference (3). Using a fineness ratio of 7, the theoretical critical cavitation index of the body without appendages is 0.0901. The critical cavitation index, σ_c, of a body at a given angle of attack is defined as the negative of the minimum value of P/q which is obtained from the pressure distribution for the body. The ratio P/q is defined by

$$\frac{P}{q} = \frac{P_t - P_s}{\frac{1}{2}\rho V^2}$$

where P_t is the total pressure at a point on the body,

P_s is the static pressure at the same depth in the free stream,

ρ is the density of the fluid, and

V is the velocity of the body relative to the stream.

Cavitation will be incipient when

$$\sigma_c = \frac{P_s - P_d}{\frac{1}{2}\rho V^2}$$

TABLE 2

Offsets for Root and Tip Sections of Tail Fins for Towed Housing, See Figure 1

All dimensions are in inches.

Root Section				Tip Section			
X	Y	X	Y	X	Y	X	Y
0	0	6.5141	0.5156	0	0	4.1877	0.3314
0.0651	0.0787	7.1655	0.5034	0.0419	0.0506	4.6064	0.3236
0.1303	0.1110	7.8169	0.4844	0.0838	0.0713	5.0252	0.3114
0.2606	0.1560	8.4683	0.4585	0.1675	0.1003	5.4439	0.2947
0.5211	0.2180	9.1197	0.4258	0.3350	0.1401	5.8627	0.2737
0.9120	0.2832	9.7712	0.3862	0.5863	0.1820	6.2815	0.2483
1.3028	0.3321	10.4226	0.3398	0.8375	0.2135	6.7002	0.2184
1.9542	0.3933	11.0740	0.2865	1.2563	0.2528	7.1190	0.1842
2.6056	0.4382	11.7254	0.2262	1.6751	0.2817	7.5378	0.1454
3.2571	0.4713	12.1162	0.1853	2.0938	0.3030	7.7890	0.1191
3.9085	0.4951	12.3768	0.1543	2.5126	0.3183	7.9565	0.0992
4.5599	0.5109	12.6374	0.1177	2.9314	0.3284	8.1240	0.0757
5.2113	0.5194	12.8979	0.0669	3.3501	0.3339	8.2915	0.0430
5.8627	0.5208	13.0282	0	3.7689	0.3348	8.3753	0
Nose Radius = 0.04779 inch Tail Radius = 0.01690 inch				Nose Radius = 0.03072 inch Tail Radius = 0.01086 inch			

where P_d is the vapor pressure of water. At a depth of 50 feet, a cavitation index of 0.0901 corresponds to a speed of incipient cavitation of 143 knots. Eighty per cent of this speed, or 114 knots, is well above the 50 knots at a depth of 50 feet anticipated in actual use.

FINS

The shape of the cross section of the fins was chosen to be that of the TMB-EPH struts described in Reference (3). The fineness ratio of the fins is 12.5. If the aspect ratio of the fins were infinite, the theoretical critical cavitation index would be 0.192 and the corresponding cavitation speed at a depth of 50 feet would be 98 knots for fins of an infinite aspect ratio. The fins, however, are of finite aspect ratio, the effect of which is to increase the cavitation speed. The relation between this increase and the aspect ratio has not been determined but, as will be noted later, the cavitation speed of the body with fins is in excess of 130 knots at a depth of 50 feet.

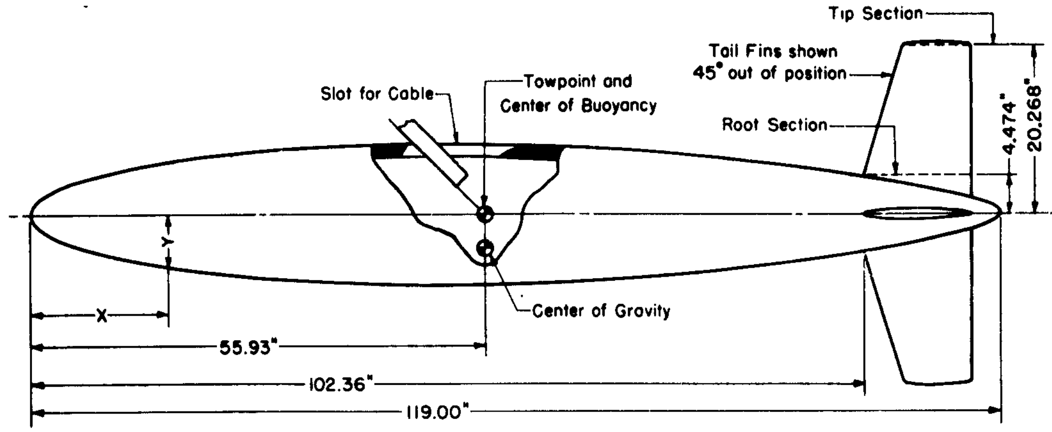

Figure 1 - Principal Dimensions of the Air-Towed Sonar Housing

The body and fins are TMB-EPH forms of fineness ratio 7 and 12.5 respectively. The contours are given in Tables 1 and 2.

The area of the tail fins was determined in the following manner. The various factors that influence the lift produced by the tail fins when at an angle of attack to the stream were arbitrarily adjusted so that the computed center of pressure of the body plus tail fins would be about one foot ahead of the center of pressure of the tail fins. It was felt that this location of the center of pressure would give sufficient static stability and satisfactory turning characteristics when towing from the center of buoyancy as shown in Figure 1. For a given attitude of the body with respect to the flow, the center of pressure is defined as the point on the axis of revolution of the body about which the hydrodynamic moments on the body are in equilibrium. The theoretical value of the lift coefficient developed by a lifting surface of infinite aspect ratio in potential flow is

$$C_L = \frac{L}{\frac{1}{2}\rho V^2 S} = 2\pi \sin\alpha$$

where α is the angle of attack,
S is the lifting area, and
L is the lift.

However, the slope, 2π, of the curve of C_L plotted against sin α is never realized in practice so that the formula for lift is empirically adjusted by insertion of a constant, giving,

$$C_L = K 2\pi\alpha$$

where K has the observed average value of 0.915 and α has been set equal to its sine. When the lifting surface is of finite aspect ratio A, the lift coefficient becomes

$$C_L = \frac{AK}{A + 2K}\, 2\pi\alpha$$

Now the hydrodynamic moment, about either the transverse or vertical axes, produced by the tail fins can be written, to an accuracy sufficient for the purpose, as

$$M = 1.4\, S_T\, l \frac{1}{2} \rho V^2 \frac{AK}{A + 2K}\, 2\pi\alpha$$

where S_T is the area of fins (extending through the body), and l is the distance from center of pressure of fins to center of pressure of assembly of body and fins. The moment produced by the body can be written, as in Reference (4),

$$M = \mathrm{Vol}\,(K_2 - K_1)\, \frac{1}{2}\, \rho V^2 \sin 2\alpha$$

where Vol is the volume of the body, and $(K_2 - K_1)$ is a virtual-mass factor. Setting the sum of the two moments equal to zero for equilibrium and setting the angle equal to its sine for small angular displacements from zero gives

$$l = \frac{(K_2 - K_1)\,\mathrm{Vol}}{1.4\, S_T \frac{AK}{A + 2K}\, \pi} \qquad [1]$$

Now $(K_2 - K_1) = 0.897$ for an ellipsoid of fineness ratio 7, Reference (5), and Vol = 9.43 cubic feet for a TMB-EPH body 17 inches in diameter. Adjusting the area and the span of the tail fins so that S_T = 3.15 square feet and A = 3.62 results in a value of 1 foot, as desired, when the values are substituted into Equation [1].

TOWPOINT

To facilitate cradling the sonar housing aboard the towing vehicle and to orient the sonar housing advantageously for its entry into the water, the model should hang horizontally from its tow cable in the air. To orient the sonar it should also ride horizontally in the water at all speeds. To accomplish this, the towpoint is located on the axis of symmetry of the body, and in a vertical line containing both the center of buoyancy and the center of gravity.

The location of the towpoint at the center of buoyancy requires that the cable pass through a slot at the surface of the body. To keep turbulence at a minumum the slot was designed to have a sharp leading edge to cause a clean break-away of the flow. The trailing edge of the slot was curved by fairing into the surface an ellipse of fineness ratio 4. The major axis of the ellipse is in the same plane as the axis of revolution of the body and is rotated about this axis through the angle subtended by the width of the slot. A cross section of the slot is shown in Figure 1. The curved trailing edge is intended to pick up the flow and divert it back to the surface of the body since the flow as a free jet leaving the leading edge could diverge slightly toward the inside of the body.

At the start of a turn, the cable pulls to one side of the axis of symmetry of the towed housing. This side pull causes the cable to bend over the sharp edge of the side of the slot and towing experience has demonstrated that this sharp bend causes the cable to fail. These failures have been successfully avoided at low speeds by attaching the cable to a rigid tow bar that extends outside the slot 6 inches when vertical. This tow bar is streamlined to the same shape as the cable fairing and is free to pivot fore and aft in the slot.

Even with the towbar, the possibility existed that the cable would bend sharply and fail where it emerged from the tow bar. However, this did not occur, indicating that the additional lever arm of the tow bar is sufficient to cause the towed housing to roll, thus alleviating the bend in the cable. At speeds as high as 50 knots it may be necessary to increase the length of the tow bar to obtain sufficient rolling moment since the tow bar at 50 knots is inclined forward at about 45 degrees.

MODEL TESTS

To demonstrate the performance characteristics of the air-towed sonar housing as analytically designed in the preceding sections, two 1/3.72-scale models were built and tested. One model was fitted with the necessary gear for towing trials, drag determination, static stability and cavitation tests and the other was fitted with 21 orifices along its length for use in obtaining the pressure distribution. The results of these tests are given in the following sections.

TOWING

Towing tests of a 1/3.72-scale model of the towed housing in the TMB high speed basin indicated satisfactory towing characteristics at speeds up to 25 knots. This corresponds to a speed of the full-size towed housing

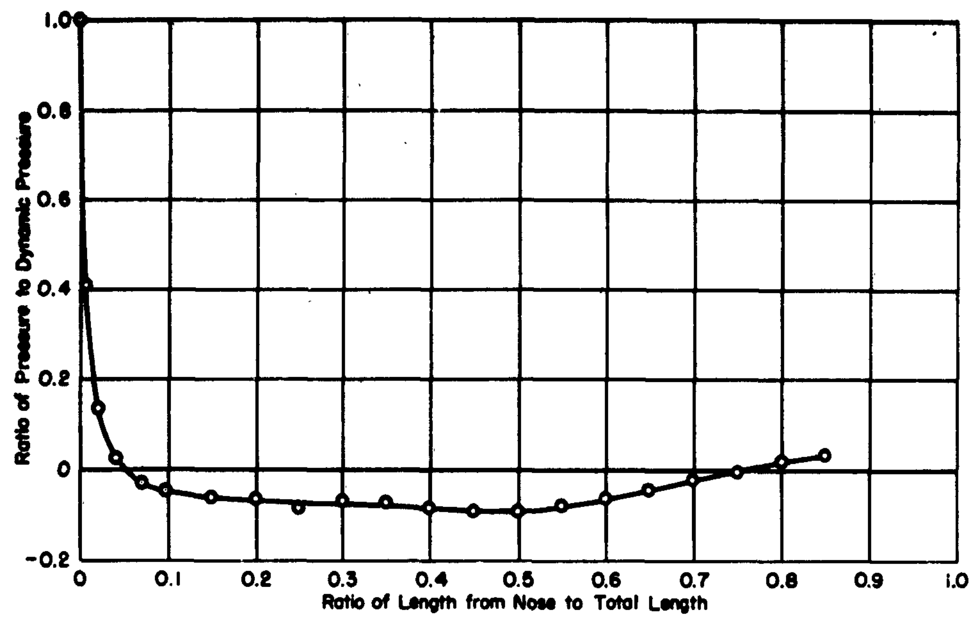

Figure 2 - The Pressure Distribution along the Air-Towed Sonar Housing

The pressures at 21 positions from the nose to the tail fins were measured on a 1/3.72-scale model. The Reynolds number was 2.6×10^6.

of 48 knots, assuming that corresponding speeds vary as the square root of the scale ratio. The towing was satisfactory regardless of the initial position of the model at the start and of the acceleration used, up to about 0.1g, in accelerating to towing speed.

DRAG

The drag coefficient, C_D, is defined as

$$C_D = \frac{D}{\frac{1}{2}\rho V^2 S_M}$$

where D is the drag, and S_M is the maximum cross-sectional area. For the 1/3.72-scale model, C_D was determined to be 0.100 at a Reynolds number, 5.96×10^6, based on length, high enough to cause transition. Effects of any possible interference between the tow cable and the towed housing are not included. At larger Reynolds numbers the drag coefficient decreases (6) so that, for the full-scale towed housing at a speed of 50 knots, at which the Reynolds number would be 6.65×10^7, the drag coefficient is estimated to be 0.07.

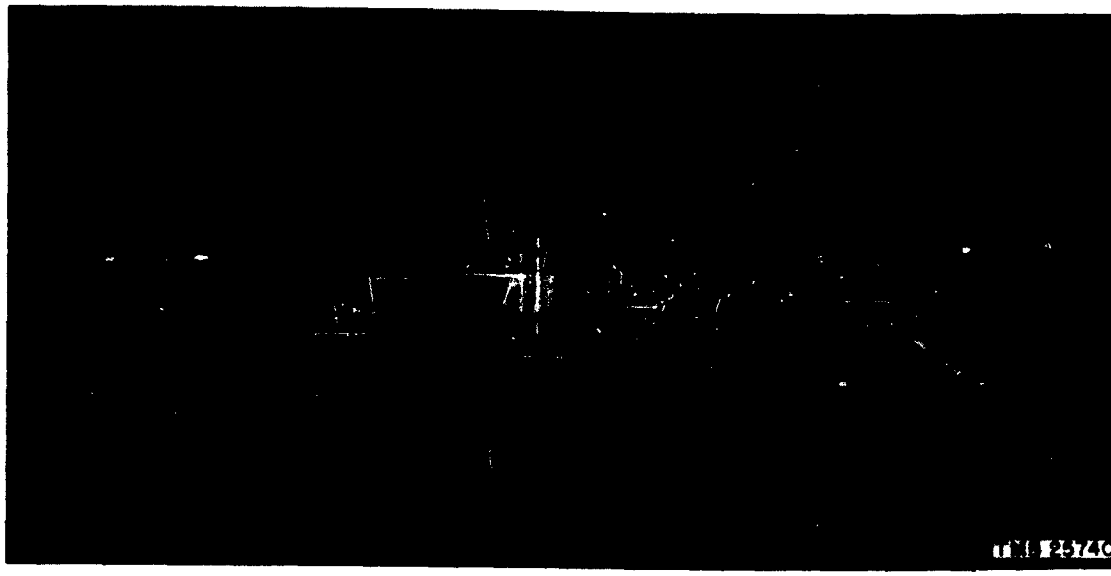

Figure 3 - The Air-Towed Sonar Housing with an Experimental Sonar Installation

This housing is 17 inches in diameter and was constructed to TMB specifications under contract with the Edo Aircraft Corporation. Full-size housings without sonar equipment have towed satisfactorily up to 39 knots.

CAVITATION

The 1/3.72-scale model was tested for cavitation in the TMB 24-inch water tunnel. The model did not cavitate at 29 knots under a pressure of 289 pounds per square foot, the highest speed and lowest pressure possible in the test. Only qualitative information therefore resulted from the test; namely, the speed of incipient cavitation for the full-size towed housing is in excess of 130 knots at a depth of 50 feet.

STATIC STABILITY

Static stability tests of the model, in which the model was free to pivot about fixed points along its length, indicated that the model was directionally stable after being displaced to any angle when free to pivot about points ahead of 55 per cent of the length from the nose. Test conditions did not permit finding the actual location of the center of pressure for small displacements to check the design location of one foot ahead of the center of pressure of the tail fins.

PRESSURE DISTRIBUTION

The pressure distribution along the towed housing was determined for a 1/3.72-scale model at a Reynolds number of 2.6×10^6 in the TMB deep water basin. The distribution is shown on Figure 2, for an angle of attack of zero degrees. The minimum pressure measured on the body indicates a critical cavitation index of about 0.095 as compared to the theoretical value of 0.0901 previously mentioned.

CONCLUDING REMARKS

Full-size towed housings have been constructed on contract to the Navy by the Edo Aircraft Corporation and the Goodyear Aircraft Corporation. A towed housing constructed by Edo, shown in Figure 3, has been towed satisfactorily in the deep water basin at the Taylor Model Basin and at sea. A number of dummy full-size towed housings, that is, housings not equipped to carry sonar, have been constructed. These dummys have been towed at sea under a large variety of sea conditions, depths, and speeds up to 39 knots. In all cases, the hydrodynamic characteristics have been entirely satisfactory.

REFERENCES

(1) BuShips SECRET ltr S68, dated 30 July 1946 to TMB.

(2) "Measurement of High Frequency Noise Produced by Cavitating Projectiles," by Robert T. Knapp, OSRD CONFIDENTIAL Report 1985, August 1943.

(3) "Calculated and Observed Speeds of Cavitation about Two- and Three-Dimensional Bodies in Water," by Hugh B. Freeman, TMB Restricted Report 495, November 1942.

(4) "The Aerodynamical Forces on Airship Hulls," by Max M. Munk, NACA Report No. 184, 1923.

(5) "The Flow and Drag Formulas for Simple Quadrics," by A.F. Zahm, NACA Report No. 253, 1926.

(6) "The Prediction of the Effective Horsepower of Ships by Methods in Use at the David Taylor Model Basin," by M. Gertler, TMB Report 576, September 1947.

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